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PREGLED RAZISKAV NA PODROČJU 3D-KATASTRA NEPREMIČNIN

A REVIEW OF RESEARCH ON 3D REAL PROPERTY CADASTRE

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IZVLEČEK

3D-kataster nepremičnin (krajsje 3D-kataster) je eno izmed pomembnih interdisciplinarnih raziskovalnih področij, na evropski in širši mednarodni ravni. Prve teoretične razprave segajo v 90. leta preteklega stoletja in se v začetku novega tisočletja še krepijo. Takrat so se oblikovali prvi mednarodni forumi za spodbujanje raziskav in oblikovanje teoretičnih zasnov 3D-katastra nepremičnin, ki jih je mogoče uveljaviti v praksi. Za spodbujanje sodelovanja med različnimi raziskovalnimi pobudami na širokem področju 3D-katastra je bila pri mednarodnem združenju FIG oblikovana delovna skupina za 3D-katastre. Pod okriljem FIG-a se je do danes zvrstilo pet tematskih delavnic oziroma mednarodnih forumov. Namen prispevka je podati kronološki pregled raziskav na področju 3D-katastrov s predstavitvijo objav, ki so pomembno usmerjale razvoj tega področja. Glavni vir so bile objave na mednarodnih forumih organizacije FIG, doktorske disertacije in znanstvene objave v mednarodnih revijah, katerih članki so opremljeni z digitalnim identifikatorjem DOI. Z raziskavami so bila v dveh desetletjih rešena številna pereča vprašanja, a obenem se pojavljajo nova, kompleksnejša vprašanja, predvsem povezana z uveljavitvijo 3D-konceptov v katastrskih sistemih posameznih držav, z večnamensko uporabo vsebinsko bogatih in kakovostnih 3D-katastrskih podatkovnih zbirk ter z združevanjem različnih prostorskih podatkovnih nizov v okviru 3D-katastra.

KLJUČNE BESEDE

kataster, nepremičnine, 3D-kataster, zemljiška administracija, LADM

ABSTRACT

The 3D real estate cadastre ('3D cadastre' in short) is an important interdisciplinary research topic at both the European and international levels. Initial theoretical scientific discussions on the 3D cadastre began in the 1990s and gained momentum at the turn of the millennium, when the first international forums were organised. Their principal aim was to develop the theoretical concepts for the 3D cadastre that would foster the research activities and their implementation. At the time, the FIG Working Group on 3D Cadastres was formed to connect the research activities in the field. To date, five international thematic workshops have been organised. This article aims to provide a chronological overview of research activities by highlighting publications that have had a significant impact on 3D cadastre research. Our main sources have been publications at the FIG international thematic forums, doctoral dissertations, and papers published in scientific journals (included in the DOI system). Many issues and challenges have been resolved, and major progress has been seen in the past two decades. Nevertheless, numerous new complex issues have arisen, particularly regarding the realisation of 3D concepts within cadastral systems in the various countries, the idea of a multipurpose 3D cadastre, and the integration of various spatial datasets within a 3D cadastre.

KEY WORDS

cadastre, real property, 3D cadastre, land administration, LADM

1 INTRODUCTION

Urban development coupled with increasingly complex cases of spatial delineation in terms of ownership and other property rights requires a new approach in land administration, which allows for registering and changing of property units, and associated information, in three spatial dimensions. The increasing physical and legal complexity of the built as well as natural environment necessitate an upgrading of the two-dimensional spatial modelling approach, which is conventionally used in national land administration systems.

The land administration domain has always been highly demanding in research terms at the international level, as countries developed their own systems underpinned by their historical background concerning land administration, their legal system, social setting as well as social needs associated with spatial development (Zupan *et al.*, 2014). The requirement for international comparability and thus structured treatment of land, and the rights, restrictions, and responsibilities associated to it, stemmed from the growing needs to develop state-of-the-art solutions in land administration. A result of many international discussions in the field was the international ISO standard 19152:2012: *Land Administration Domain Model (LADM)*, adopted in 2012.

The purpose of this paper is to provide a broad review of internationally recognised publications and thus present the evolution of the 3D property cadastre over recent decades. Based on these publications we analysed the topics that are currently the focus of international research undertaken in this field.

2 METHODOLOGY AND RESOURCES APPLIED

Researchers and developers in various fields are concerned with developing 3D cadastre concepts as well as technical and legal solutions for its implementation. They all focus on a very specific domain, i.e. real property cadastre, which thus brings together the latest progress achieved worldwide. The main resources for this study were the available resources and records of the Thematic Working Group on 3D Cadastres, established by the International Federation of Surveyors (FIG)¹, which back in 2001 organised its first international forum with a view to help to develop solutions in the 3D property cadastre. An important resource for our work was publications in two special issues of the international scientific journal *Computers, Environment and Urban Planning* from 2003 and 2013, respectively, where also an overview of discussions under FIG until 2012 (Oosterom, 2013) was published, and publications in *ISPRS International Journal of Geo-Information* with a special issue *Research and Development Progress in 3D cadastral systems* of 2017. Additionally, we reviewed relevant PhD researches and English papers that appeared in other international journals published with the well-established *Digital Object Identifier* (DOI). The *CrossRef* reference linking service was used, which is one of the solutions that publishers use to create DOI and include journals into an extremely large international community of electronic scientific and professional publications (see also Koler Povh and Lisec, 2015).

3 RESULTS – OVERVIEW OF 3D PROPERTY CADASTRE DEVELOPMENT

The beginnings of intensified efforts to develop the 3D real property cadastre date back to 1994 when FIG Working Group 7.1 was initiated, which in 1998 published the vision of developing future cadastral

¹ *Fédération Internationale des Géomètres*: www.fig.net.

² *CrossRef*: www.crossref.org, last reviewed 10 January 2018.

systems entitled *Cadastre 2014* (Kaufmann and Steudtler, 1998). This document underlined the role of the cadastre as an important stakeholder to support sustainable development and decision-making concerning spatial decisions. The document provides important definitions and, inter alia, instead of a parcel (parcel-based cadastre), introduces the more general term “(land) object” as the basic real property element to which rights, restrictions, and responsibilities apply. The cadastre should give enough information to provide a complete picture of the situation of land, legal security, and transparency regarding the rights, restrictions, and responsibilities associated to cadastral objects. The end of separating between descriptive and graphic representations in the cadastre and the introduction of computer modelling, replacing analogue cadastral mapping, were projected, both because of the rapidly developing information technology. These new definitions and orientations encouraged, among other things, the discussion on introducing the third spatial dimension into real property records.

3.1 Studies in 3D property cadastre between 2000 and 2010

The first results of the studies in the research domain of 3D real property cadastres, which strongly affected further international research efforts, were published at the turn of the millennium (Stoter, 2000; Stoter and Zevenbergen, 2001). The authors find that the 2D system to register the legal status of real estate objects in many cases does not provide enough legal security regarding the rights and restrictions on real property objects and it can also no longer satisfy other functionalities of the land administration system.

3.1.1 Early internationally recognised studies, discussions, and publications

The previously mentioned research work at the Delft University of Technology, the Netherlands, was an introduction to the first workshop on the topic of real property cadastres in 2001, organised by FIG, which sparked interest and strengthened the topic of 3D cadastres in the research sphere. The workshop introduced the classification of the research field into legal, technical, and organisational aspects, which have been preserved, almost without modification, to this day. The workshop featured presentations on land administration systems in individual countries, existing ways of solving complex cases of real property registration where there is a need for vertically stratified allocation of rights, and on possibilities for further development (Grinstein, 2001; Huml, 2001; Menda, 2001; Onsrud, 2001; Ossko, 2001; Rokos, 2001; Viitanen, 2001). Among them was the presentation of the then introduced Building Cadastre in Slovenia (Pogorelčnik and Korošec, 2001).

The conclusions were drawn by Lemmen and Oosterom (2003) as an introduction to the special issue of the international journal *Computers, Environment and Urban Planning*, which published selected papers from this workshop. In his work, Molen (2003) argues that changes in complex systems, such as that of the cadastre, always require organisational development of institutional conditions and that they need to follow technological progress. The dilemma, i.e. the difference between legal objects and objects representing physical structures in space, is particularly underlined. Onsrud (2003) presented a new regulation in Norway, which was being adopted at the time, allowing for registering 3D properties to settle rights and restrictions on “construction properties”. The possibility of combining this regulation with the existing one, based on the condominium concept, was presented. Back then, the real property registration system in Norway was still completely based on 2D parcels, partially even in analogue form.

The author saw no real possibility in the near future to technically register legal 3D property units as 3D objects. A major challenge in 3D cadastres, which remains pertinent today, was how to efficiently model cadastral data in information systems, as reflected in several papers published in the aforementioned special issue (Billen and Zlatanova, 2003; Stoter and Ploeger, 2003; Tse and Gold, 2003). Tse and Gold (2003) propose using a Triangulated Irregular Network (TIN) to model geometry and topology of 3D cadastral objects, which they justify by the feasibility of the proposed solution. Billen and Zlatanova (2003) also study how to model spatial objects, with an emphasis on spatial relationships. Stoter and Ploeger (2003) present the ways of developing conventional systems towards a 3D cadastre.

The doctoral thesis by Stoter (2004) is the first extensive research work on the 3D cadastre, which comprehensively discusses its technical aspect, while also delving into its legal and organisational aspects. It presents several practical cases in the Netherlands, where the two-dimensional approach in land administration is no longer meeting the demands for transparent real property registration. By analysing the state of land administration internationally and a detailed analysis of selected countries, she found that up to the point no country had developed a system for 3D registration of property units; moreover, it was not actively developed anywhere. She underlined and made clear the rationale to introduce 3D cadastres in selected study cases. She particularly addressed modelling, administration, and presentation of data on real properties in a 3D environment. Furthermore, she discussed the capacity of information technology for establishing databases, solutions for 3D geometry storage, procedures for validating the accuracy of the information recorded, and data administration functions of the time. In her research for her doctoral thesis, she developed three cadastral data models. The first one is an upgrading of existing cadastral systems, by storing links to 3D data, which are stored separately. The hybrid model preserves the existing role of the traditional 2D cadastre as the basis onto which rights, restrictions, and responsibilities are bound, but it allows for registration of 3D objects to show more clearly the situation regarding rights and restrictions in space in special cases. The real 3D cadastre allows for registration of volume parcels. 3D parcels assume the role of cadastral objects – the parcels in the cadastre are no longer defined as 2D polygons, but rather as 3D bodies, while in the case of traditional parcels lacking the vertical division they are defined as upright towers, which are not vertically limited. Hence, this is a volumetric division of the entire space with 3D property units.

Here, the activities of the United Nations Economic Commission for Europe should be mentioned, which in 2004, to support the development of efficient land administration systems, published guidelines focusing on real property units and object identifiers (United Nations Economic Commission for Europe, 2004), which importantly underlines the role of modern cadastre from the economic viewpoint. This document should help to align terminology and understand the differences between the systems of individual countries, facilitating international collaboration and data exchange in the field. It also touches upon the problem of the third spatial dimension of real property units, the condominium or strata title, and mineral extraction sites.

3.1.2 3D cadastre and data models

Rather than introducing the storage of the additional spatial dimension, the introduction of the 3D cadastre entails radical changes of the entire cadastral data model. The start of 3D cadastre development

in the late 1990s coincides with the intensive period of introducing computer modelling in land administration as well. In 2003 the first proposal for a cadastral data model³ was proposed to unify the concepts and data models of national systems (Oosterom and Lemmen, 2003). 3D cadastre is highlighted as a special case, defined as a possible upgrade or extension of the CCDM, along with the temporal aspect (Oosterom, Lemmen and Molen, 2004). In the latter case, the authors refer to the study by Stoter (2004).

3D models of physical objects (buildings and infrastructure) are not included into the Core Cadastral Domain Model (CCDM), but they are included into the set of relevant and related topics. The primary guidelines in developing CCDM are the inclusion of a maximum range of common characteristics of cadastral systems worldwide, as set out in *Cadastrre 2014* (Kaufmann and Steudtler, 1998) and specified in international standards (Oosterom *et al.*, 2006). Great attention was given to the determination of its thematic scope; the authors developed CCDM in a very narrow manner but at the same time predicted the option of various thematic extensions. Such design facilitates the adjustment of the model to various systems around the world and at the same time preserves the basic level of comparability, i.e. common characteristics of cadastral systems. Further development of the model made it possible to include 3D parcels using the concept of bound surfaces, but with the limitation, i.e. that the area in question is recorded exclusively either in 2D format or 3D format. CCDM was the predecessor of the LADM model⁴. This new name of the model was first mentioned in 2008 (Groothedde *et al.*, 2008). FIG proposed the model to become an ISO standard (Lemmen, Oosterom and Uitermark, 2009) and since 2012 it has been officially published as ISO 19152:2012 standard (LADM, 2012).

In the initial period of research activities concerned with 3D property cadastre, studies and analyses of 3D geo-objects to be used in the 3D cadastre were carried out (Billen and Zlatanova, 2003; Tse and Gold, 2003). Stoter and Oosterom (2002) present the possibilities of modelling geo-objects in DBMS, providing the basis for managing cadastral systems from the perspective of information technology. Studies discuss management of 3D geo-objects in DBMS⁵ in terms of modelling, functionality, and visualisation (Zlatanova, 2006; Khuan, Abdul-Rahman and Zlatanova, 2008). 3D objects can be represented as tetrahedrons, polyhedrons, and multipolygons. In these papers, authors argue that 3D geo-objects can, indeed, be stored, as DBMSs support the storage of spatial features, such as points, lines, and polygons in 3D space, but difficulties arise in terms of their administration, analysis, transmission, and visualisation. These problems stemmed from the fact that, at the time, DBMS did not yet support the data type of volumetric 3D objects and thus did not allow for management of such data and analyses in a 3D environment.

The checking of compliance of data with their formal definition is one of the most important aspects of data management; this also refers to 3D spatial data (Kazar *et al.*, 2008; Ledoux, Verbree and Si, 2009). This is highly significant in reference to 3D cadastrals as well (Karki, Thompson and McDougall, 2010). Rather than focusing on the internal validity of individual objects, the authors addressed them in the context of a 3D cadastral system, where interrelationships between 3D objects and 2D parcels are important.

Time, i.e. the temporal aspect, as the fourth dimension of reality, is among the key cadastral data components. The first explorations in this field (Oosterom *et al.*, 2006) deal with time-sensitive cases and focus

³ Core Cadastral Domain Model (CCDM)

⁴ Land Administration Domain Model

⁵ Database Management System (DBMS)

on the meaning of adding the temporal component to the cadastral data model, regardless of it being a 2D or a 3D cadastre. The temporal aspect is also addressed in the framework of the LADM standard that was proposed at the time (Döner *et al.*, 2008) and investigated on the case of registering underground infrastructures in various countries. The authors establish the relationship between the legal object and the physical object of underground utility networks by buffering, and at the same time distance themselves from registering the geometric description of the physical object in the cadastre. Notably, the authors argue that land administration systems have from the very beginning dealt with three dimensions as well as the temporal dimension within the current technical structure, i.e. as attributes. The temporal part of the data model is thus based on registering situations in time, i.e. “snapshots”, which is basically done in most cadastral systems, or registering the initial situation and all ensuing events.

3.1.3 Legal aspects of the 3D cadastre

In early investigations on the 3D property cadastre, the legal topic was given significant less consideration than studies focusing on information technology. The first comprehensive and extensive study concerned with the legal aspects of the 3D property cadastre in the broader international context was done in Sweden (Paulsson, 2007), where the author dealt with the basic problem of defining a 3D property unit. With the purpose of universality, she defines it as a spatial unit that is delimited both horizontally and vertically. She divides rights, restrictions, and responsibilities, which are distributed in space, into condominium ownership, i.e. strata title, and independent 3D areas of rights. The strata title is treated as an established means of settling rights, which are delimited both horizontally and vertically, and therefore it is thoroughly examined in this work. The author comprehensively and systematically examines, and compares, four selected legal systems, which have different traditions and use different property right registration procedures in terms of their horizontal and vertical division: Germany with its traditional system of strata-title ownership and codified law, Sweden with a detailed legal system and new legislation allowing for registration of independent 3D property units, and Australian federal states New South Wales and Victoria, with ordinary law and legislation allowing for establishment of both strata title and independent 3D property units.

3.1.4 Organisational aspect – 3D cadastre situation and perspectives

Many publications from the first decade of intensified research on 3D property cadastres represent the situations and perspectives of introducing the 3D property cadastre in the individual countries. Most of them analyse the existing cadastral systems from their legal and technical aspects, complex cases where property registration should be tackled in three dimensions, and the options of 3D cadastre introduction in individual countries. These include specific conceptual designs, nevertheless, in all cases the technical solutions are, for the time being, practically not yet directly applicable.

The possibilities of 3D cadastre establishment were studied in Israel (Benhamu and Doytsher, 2003), where solutions were sought on the principle of multi-layered cadastres, which could contain, along with the data layer for traditional parcels, the data layers for structures above and below the surface (Benhamu and Doytsher, 2001; Benhamu, 2006). Technical challenges, related to Israel and beyond, were discussed by Peres and Benhamu (2009), when the efforts towards operational⁶ implementation of

⁶ In this paper, the term “operational” refers to the actual use/implementation of something in the cadastral system of a certain country.

3D cadastre had already strengthened. It is also worth mentioning China, where private property can be established on built structures only. Tang and Yang (2009) developed a conceptual model to enable registration of 3D property units, while recognising that, at the time, it was not yet feasible due to the lack of data and non-existent information and technological solutions for storing and managing 3D data. The literature reveals that Australian federal states New South Wales, Victoria (Paulsson, 2007), and Queensland (Stoter, 2004) have a tradition of a particular statutory scheme and registration of 3D property units. These can also apply to non-built-up areas above or below the Earth's surface. From the perspective of storing data on property unit geometry, the property registration system in all the federal states mentioned was entirely based on 2D concepts.

In this period Norway adopted legislation allowing for establishment of independent 3D property units (Valstad, 2010). The basic characteristics of this legislation were previously addressed by Onsrud (2003). Registration of independent 3D real property units is possible only for the purpose of registering engineering objects (Valstad, 2006), similarly as in Sweden (Eriksson, 2005; Paulsson, 2007). The cadastral system in both countries technically did not allow for digital registration of 3D geometry of property units. Registration of a single apartment as an independent 3D unit is not possible neither in Sweden nor in Norway. For this, the condominium registration has to be used, which regulates relationships between individual property units of a building. It should be underlined that both countries have a single land administration system, which was years ago established by combining the former dual system (legal and technical). This fact is stressed because of the organisational and institutional aspects of introducing the 3D cadastre and other major changes into land administration.

Contrary to the previously mentioned countries, which are in this period addressed more often due to their way of managing and registering 3D property units, the Netherlands kept the traditional organisation of its cadastral system. For several decades, the Netherlands has had a single land administration system inside one organisation (previously it had a dual system consisting of a land cadastre and a land register). The fact that the Netherlands frequently comes up in studies is the result of Dutch researchers' efforts and collaboration of the academic sphere and the surveying administration, which at the beginning of the decade greatly accelerated studies into 3D cadastres (Stoter and Ploeger, 2003; Stoter and Salzmann, 2003; Stoter, 2004).

In the first decade, by introducing the Building Cadastre, Slovenia set the basis for developing the 3D cadastre (Pogorelnik and Korošec, 2001; Rijavec, 2009), but to date there have not been any major steps taken in this direction, while a major problem is also the poor link between land parcels and buildings, deficiencies in cadastral recording of engineering structures and infrastructural works (that are not buildings), and the insufficient data model of the Building Cadastre (see also Drobež, 2016; Drobež *et al.*, 2017).

In terms of operational implementation of the 3D real property cadastre in practice, the literature at the end of the decade often highlights that further development in all relevant fields is necessary, with the exception of the legal field in some countries, where there are practically no legal constraints. Interestingly, the study by Çağdaş and Stubkjær (2009), analysing methodological approaches used in doctoral researches concerned with cadastral system development, does not recognise the 3D cadastre nor the aforementioned doctoral studies (Stoter, 2004; Paulsson, 2007) as an important part of modern cadastre development.

3.2 Studies concerned with the 3D cadastre after 2010

In 2011 a survey was conducted among the members of FIG Working Group on 3D Cadastres, with 36 member states of this group taking part (Oosterom *et al.*, 2011). The survey's content focused on inventorying the situation by countries in 2010 and their expectations for 2014. The results of the survey importantly contribute to studies on 3D cadastres, as they allow free access to the extensive set of data on cadastral systems in many countries. The authors of the survey find that countries have different cadastral systems, where the incongruent perception of the 3D cadastre stems from. The differences are mostly regarding the understanding of the connection of traditional 2D parcels and 3D property units with physical structures. By the time no country had developed the system for storing and managing 3D data on property units in cadastres. Most of them were highly restrained in their plans and expectations for 2014. In 2014 representatives of 31 replied to the second, updated survey on the condition and expectations in 3D cadastre for 2018 (Oosterom, Stoter and Ploeger, 2014). In all countries, where the legal system allowed for registration of 3D property units, the ways of data registration, storing, and management were still based on 2D cadastre. What the countries had in common was that digital cadastral databases were mostly "incongruent" with the standard scheme ISO 19152:2012 (LADM, 2012). China stands out in terms of storing 3D data in digital format, stating in the replies to the survey that their database allows for storing, validating, and managing the 3D geometry of property units. Nevertheless, In the Chinese case we find an extremely small total number of parcels given the size of the country, so we assume that this situation is valid only for limited (urban) areas of China. Later studies (Guo *et al.*, 2013; Ho *et al.*, 2013; Dimopoulou, Karki and Roič, 2016; Stoter *et al.*, 2017) also confirm that at the beginning of the decade China did not have a fully operational 3D cadastral system.

In 2011, the second workshop on 3D cadastre took place in the Netherlands, 10 years after the first one. Interestingly, the next, third, workshop was planned to take place in two or three years, but it was held the very next year, which shows the growing international interest in research and knowledge exchange in this field. The report from the 2011 workshop (Banut, 2011) breaks down the situation in individual development fields of the 3D cadastre, divided into legal aspects, first registrations of 3D property units, administration of 3D spatial data and visualisation, transmission of data, and accessibility of data on 3D property units:

- The problem of terminological incongruency and various definitions of 3D cadastre was highlighted in the legal field.
- More than two thirds of the papers at the 2011 workshop describe land administration systems and different regulations for vertical stratification of property units from the perspective of current studies and data models.
- The field of managing digital 3D spatial data, particularly the fields of analyses and operations in DBMS and GIS⁷, has been strongly lagging behind the field of 3D visualisation of spatial data, which made strong progress in the first decade of this millennium. The importance of electronic accessibility of 3D property cadastral data and 3D web-based visualisation techniques is underlined.

The thematic focus of the third workshop in 2012 was development and best practices in 3D cadastre (Oosterom, 2012). The need for more studies and comparative analyses of legal schemes in various coun-

⁷ *Geographical Information System*

tries and the requirement to use existing standards, both in terms of modelling property units (LADM) and modelling physical spatial structures in land administration information systems, were expressed. Inter alia, the meaning of visualisation of 3D property objects was stressed, as the needs and challenges are different than with visualisation of more commonly used 3D models of cities and landscapes.

Based on the papers from FIG workshops and conferences in 2011 and 2012, Oosterom (2013) provides an overview of development in 3D cadastres and presents the most important topics for further studies. We particularly underline the topics that remain topical at a global level today:

- As mentioned earlier, the lack of studies concerned with legal aspects was discussed by Paulsson and Paasch (2013) after reviewing 156 publications in English between 2001 and 2011. They identified the lack of terminological and comparative studies that would cover several countries and several 3D cadastre legal schemes.
- Heights and vertical systems in 3D cadastres were addressed in detail for the first time by Navratil and Unger (2013). They represented the general problems of vertical reference systems, restrictions, and demands of 3D cadastres, also on practical cases. The greatest attention is given to the analysis of strengths and weaknesses of using absolute and relative heights in the 3D cadastre.
- An important element, which greatly influences the dynamics of establishing the 3D cadastre, is its cost–benefit relationships. One of such studies, with reference to Trinidad and Tobago, found a positive cost/benefit ration in urban, densely populated areas and the oil mining areas (Griffith-Charles and Sutherland, 2013). The authors conclude that it is reasonable to explore the possibility of introducing the 3D cadastre in selected areas only, where benefits exceed costs.
- Operational implementation of 3D cadastres, inter alia, requires the specification of clear rules regarding division of space into 3D property units, their modelling in the 3D environment, and, at the same time, coupled with validation procedures as to their compliance with the rules set. This is much more difficult in three spatial dimensions, as the set of rules is more extensive and the procedures of compliance verification are more complex than in the conventional 2D cadastre. Karki, Thompson and McDougall (2013) thoroughly studied this field and developed specific solutions and a set of challenges and questions that remain to be solved. They conclude that the development of land administration systems towards the 3D cadastre is not possible in a short period of time. One of the solutions is the gradual adaptation of existing systems, as argued by Guo *et al.* (2013). On the case of the Chinese cadastre, authors stem from the existing legal system and the 2D cadastral data model, into which they include elements of the 3D cadastre. This paper is also interesting when compared to the results of the previously mentioned research on 3D cadastre development by Oosterom, Stoter and Ploeger (2014), where we could have made the wrong assumption the China had had a fully operational 3D cadastral system before 2014.
- The comparison of cadastral systems of various countries is difficult due to their diversity. Pouliot, Vasseur and Boubehrezh (2013) compared cadastral system models in France and Canada with a focus on the third spatial dimension based on the LADM standard (2012). They identified, as the most demanding part, the transformation of the data model of the individual system into the standard LADM scheme, which then allows for direct comparison between various cadastral systems, their classes, and attributes. They propose and justify the inclusion of volumetric geometry in the standard, which would increase the applicability of the LADM standard in the 3D cadastre as well.

The papers in the fourth FIG workshop on the topic of 3D cadastre in 2014 were mostly technically oriented, regardless of the voiced concerns about the lack of consideration of the legal problem (Paulsson and Paasch, 2013):

- At the workshop, the legal aspect was addressed as a main topic only in one presentation, on the case of the national study for Poland (Karabin, 2014).
- There was a growing consideration of the ISO standard LADM (2012) and the open standardised data model CityGML by OGC⁸ (CityGML, 2012), which were found, in a combination or separately, in eight publications. Compared to the previous workshops, the number of studies and presentations of national cadastral systems dropped. Two publications were particularly interesting (Almeida *et al.*, 2014; El-mekawy, Paasch and Paulsson, 2014), as they discussed voluntary geographical information and linked BIM⁹ solutions with the 3D cadastre. These two topics were presented as a challenge to the 3D cadastre, as both areas are intensively studied in the wider area of geosciences. Building Information Modeling (BIM) provides a potential for developing a 3D cadastre, and together they provide an important area for future research (Rajabifard, 2014).
- The content of publications shows the growing interest in studies on 3D visualisation (Navratil and Fogliaroni, 2014; Pouliot, Wang and Hubert, 2014; Ribeiro, de Almeida and Ellul, 2014) which is confirmed by two extensive doctoral dissertations from the period (Shojaei, 2014; Wang, 2015). Wang (2015) focused on evaluating the suitability of 3D model visualisations for the case of strata title, while Shoaei (2014) mostly analysed user requirements and needs.

3.2.1 Challenges related to the 3D cadastre from a legal perspective

Even though the legal aspect of the 3D cadastre was not given significant consideration at the 2014 FIG workshop, this research domain remains topical at the international level. In land administration and property records the concepts of physical and abstract space meet, where rights, restrictions and responsibilities are associated to “abstract” spatial units. With incomplete knowledge of the field they can be equated based on coincidence of boundaries of physical structures and rights, i.e. restrictions in some cases. The division of space from the legal aspect is fundamentally abstract, while its link with physical space is established in various forms and from various reasons, while it varies from one legal system to another. The 3D cadastre domain is mostly directed towards treating partitioning of buildings into property units, as a relationship between space of legal significance and physical space and its structures (Aien, 2013; Aien *et al.*, 2013, 2015) therefore physical boundaries are often equated with legal boundaries. In these studies, the authors developed the 3DCDM data model¹⁰, which combines the physical and legal aspects of dividing space for the needs of the 3D cadastre.

The evolution of the 3D cadastre in the first decade led to discrepancies regarding legal definitions of a property in three dimensions (Paasch and Paulsson, 2012). The authors find that the latter causes problems also in research, where inconsistent definitions of basic terminology limit the possibilities of comparative analyses and studies. They emphasise that the legal definition of a property in three dimensions must be broad enough to be acceptable in most legal systems. Secondly, the definition must provide a clear and unique definition of the property and delimit it from the traditional property in two dimensions. The authors propose using a universal definition of 3D properties, as previously proposed by Paulsson (2007).

⁸ Open Geospatial Consortium: <http://www.opengeospatial.org/>

⁹ Building Information Modelling

¹⁰ 3D Cadastral Data Model

Among interesting legally-oriented studies is that by Ho *et al.* (2013) where the authors argue that the significant barriers to 3D cadastre implementation lie not in technology, which is developed well enough, nor in legal systems, as in many countries, they allow for registration of 3D property units – instead, there must be a limiting factor, inertia, preventing faster 3D cadastre implementation. Authors explain and break down this inertia by introducing the institutional theory and justifying that the reasons for slow changes lie in the slow adaptability within organisations responsible and the strongly rooted 2D concept in land administration systems. Oosterom and Lemmen (2015) stress that 3D (and 4D) administration are among the most significant development trends in land administration and thus also the LADM standard. They present the studies arising from the first thematic workshop after the publication of the LADM standard, among which two studies treat the topic of 3D cadastre development in Korea and Malesia (Lee *et al.*, 2015; Zulkifli *et al.*, 2015).

3.2.2 Challenges of introducing the 3D cadastre

A special topic in developing the 3D cadastre is its operational implementation. The first studies concerned with the topic were done under the Dutch project intended to help the transition to the 3D cadastre, which is based on two implementation phases (Stoter, Oosterom and Ploeger, 2012; Stoter, Ploeger and Oosterom, 2013). The first phase was to gain experience, adjusting its solutions to existing legal and technical frameworks. Its implementation part relates to the possibility of property registration based on a PDF document, which contains 3D geometry and is connected with other data about the property through a link in the database. The assessment of registration and system maintenance costs is interesting as, for new buildings, they should not be higher than the existing registration costs. Today, the first phase of implementing 3D cadastre allows for solving some complex situations, particularly to unambiguously show the division into property units, while the existing 2D land administration system basically remains the same. The second phase is far more ambitious, as it provides for 3D cadastre establishment, allowing for a comprehensive digital registration of property units, including geometry, in the form of 3D objects (volumetric bodies) directly in the cadastral database. Many issues arise in the second phase related to validation of 3D data geometries, required positioning and geometrical accuracy, data formats, inclusion of curved surfaces, partially open elements, etc. (Stoter *et al.*, 2017).

The project of 3D cadastral modelling in Russia began in collaboration with Dutch researchers. They developed a prototype that mostly focuses on the manner of modelling and representing 3D property units. In their designs, they defined a pilot project in a small area, where they would approach the real implementation of registration. Vandysheva *et al.* (2012) underline the meaning of automated control during the entry of new property units in the sense of compliance with previously set rules. Despite the intensified efforts for 3D cadastre establishment and land administration system upgrade in recent years, the Russian cadastral system is still based on two spatial dimensions (Ilyushina, Noszczyk and Hernik, 2017).

3.3 Current topics and studies on the 3D cadastre

The last FIG workshop on 3D cadastre took place in 2016. The fact that this research domain is active is also proven by the increased number of papers (31) compared to the previous workshop (25). Extended papers were collected in a special issue of the international journal *ISPRS International Journal of Geo-Information* entitled *Research in Development Progress in 3D cadastral systems 2017*.

Most notable is the major body of research around the analysis of situations in individual countries and the different possibilities for developing land administration systems, particularly publications focusing on technical solutions of modelling 3D property units in land administration information systems (Araújo and Oliveira, 2016; Dimas, 2016; Soon, Tan and Khoo, 2016; Gulliver, Haanen and Goodin, 2017). Other publications in internationally renowned journals also touch upon this field. Aien *et al.* (2017) underline six of the most established data models in the cadastre, where, due to the differences in land administration systems, many data models have emerged. The authors particularly highlight three of them (LADM, ePlan, ArcGIS Parcel Data Model) and analyse them in detail in terms of their usability for 3D cadastres. Data model 3DCDM, which was as part of his doctoral research developed by the lead author, is not included nor mentioned in the study. The authors conclude that some data models discussed allow for modelling 3D property units, but each of them has important limitations for 3D cadastre development.

At the research level, the legal domain of studies is strongly represented (Kitsakis and Dimopoulou, 2017; Vučić *et al.*, 2017), headed by an extensive comparative study of selected countries (Kitsakis, Paasch and Paulsson, 2016; Paasch *et al.*, 2016). Kitsakis, Paasch and Paulsson (2016) present the legal definition of 3D property units in various countries (Austria, Brazil, Croatia, Greece, Poland, and Sweden) and the plans for future development. Of these countries, Sweden is the only one that does not restrict registration of 3D property units in its legal system; however, data management in Sweden, and elsewhere, is still based on 2D concepts.

Another interesting study, by Janečka and Souček (2017), is concerned with data modelling in management in 3D cadastres. The authors discuss the current situation in the wider area of 3D geoinformatics, which covers concepts, data models, standards, and operations related to 3D spatial data. The emphasis is on the current capacities of spatial databases in view of modelling and managing 3D spatial data. The connection or integration of BIM data with the 3D cadastre data model is extremely topical. In relation to BIM data, a growing number of studies is focusing on modelling indoor spaces of buildings for the needs of registering property units (Oldfield *et al.*, 2016; Atazadeh, 2017). Atazadeh *et al.* (2017) treat BIM as the basis for managing rights and restrictions associated to buildings. They propose the extension of the data model so that it could support the input of data on the rights and restrictions inside buildings and their management. Among other, the authors address the topical questions of relationship of 3D units of legal significance and a building's physical model. Along with strengths, the authors discuss the limitations of the proposed approach, which include institutional barriers, the too extensive data structure, and the discrepancy between the planned structure and the structure actually built.

The research by Zlatanova *et al.* (2016) is oriented towards modelling indoor spaces of buildings, where in 2014 the standard OGC – IndoorGML (2014) was used for the first time as part of the studies into the 3D cadastre. In this paper the authors discuss the options for linking the aforementioned standard with the LADM standard. Further research in this area was done by Alattas *et al.* (2017). The IndoorGML standard is based on a multi-layered space-event model, which was originally intended for indoor navigation, as proposed in 2009 (Becker, Nagel and Kolbe, 2009). This group of authors also led the development of CityGML, the previously developed standard for modelling cities and landscapes in the 3D environment. The IndoorGML standard introduces a cellular approach to modelling indoor

spaces of buildings, using the duality principle (Munkres, 1984), coupled with mathematical graphs. It allows for the operation of the optimal path searching algorithms to support navigation as well as other algorithms based on topological relationships among the objects. The standard allows for extensions of the data model in the form of extension modules for various fields. Kang and Li (2017) particularly stressed the possibility of implementing the extension module of the IndoorGML standard to be used in the 3D cadastre. Linking outdoor city models and models of buildings' indoor spaces has been recognised as a research problem also by the United Nations Committee of Experts on Global Geospatial Information Management – UN-GGIM (2015).

4 CONCLUSIONS

The beginnings of introducing the term 3D cadastre date back to the publishing of the document *Cadastre 2014* (Kaufmann and Steudtler, 1998). To facilitate the materialisation of these goals, in 2001 FIG held the first workshop, which encouraged research into the 3D cadastre. The various aspects of developing 3D cadastres were set more clearly: legal, technical, and administrative, of which the first two are more strongly represented in studies. The first decade was characterised by many analyses of land administration systems in individual countries and proposals for their upgrading. They collectively concluded that additional development in all the mentioned research fields are needed to establish 3D registration.

Doctoral dissertation by Stoter (2004) left an indelible mark on the technical aspect of studying 3D cadastres. Most studies thereon related to her findings, definitions, and proposals. Two countries stand out in the legal field: Sweden, which in 2004 introduced the option of registering 3D property units in its legal system, and Australia with a longstanding tradition of possibilities to register independent 3D property units. The doctoral dissertation by Paulsson (2007) is among the most acclaimed studies into legal systems related to the 3D cadastre, providing a comprehensive review and insight into the legal aspect of the 3D cadastre. *Cadastre 2014* set off initial designs of CCDM to unify the key components of land administration systems, with open possibilities for including specificities, and characteristics of individual countries. This is the direct predecessor of the international standard LADM (2012), which basically does not restrict the evolution of the traditional 2D cadastre into the 3D cadastre.

The last decade of studies concerned with the 3D cadastre has been characterised by the publication of standards LADM (2012), CityGML (2012), and IndoorGML (2014). Most studies in this period study the possibility of using the standards, analyse the strengths and weaknesses of the individual standards and compare them, while fewer studies tackle the legal aspect, as previously found by Paulsson and Pasch (2013). During this time, Dutch researchers importantly contributed to implementing the concepts of the 3D cadastre into practice; in the future it will be interesting to see how a growing number of countries will decide to include the third dimension in the cadastre. Research challenges in 3D cadastres also relate to the integration of data from other domains, particularly research regarding the use or inclusion of BIM data in the 3D data model, and vice versa. The treatment or modelling of indoor structure of buildings is also topical; it is complex both from the aspect of data structure and complexity of data models as well as from the aspect of data acquisition and integration of models of indoor spaces and outdoor models of cities and landscapes (UN-GGIM, 2015).

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PREGLED RAZISKAV NA PODROČJU 3D-KATASTRA NEPREMIČNIN

OSNOVNE INFORMACIJE O ČLANKU:

GLEJ STRAN 249

1 UVOD

Urbani razvoj in z njim vse bolj zapleteni primeri razmejevanja prostora z vidika lastninske ali drugih pravic na nepremičninah zahtevajo nov pristop v zemljiški administraciji, ki omogoča evidentiranje in spreminjanje nepremičninskih enot ter z njimi povezanih podatkov v treh prostorskih razsežnostih. Vse večja fizična in pravna kompleksnost grajenega, pa tudi naravnega okolja narekuje nadgradnjo modeliranja prostora v dveh razsežnostih, ki je tradicionalno navzoče v nacionalnih sistemih zemljiške administracije.

Področje zemljiške administracije je bilo od nekdaj zelo zahtevno za raziskave na mednarodni ravni, saj so države razvile svojevrstne sisteme, ki so med drugim zelo pogojeni z zgodovinskim ozadjem zemljiške administracije, s pravnim sistemom in družbeno ureditvijo, pa tudi s potrebami družbe na področju upravljanja prostora (Zupan *et al.*, 2014). Zaradi vse večjih potreb po razvoju sodobnih rešitev na področju zemljiške administracije se je pojavila zahteva po mednarodni primerljivosti in s tem po strukturirani obravnavi zemljišč ter pravic, omejitev in odgovornosti (angl. *rights, restrictions and responsibilities*) na njih. Rezultat številnih mednarodnih razprav na tem področju je v letu 2012 sprejeti mednarodni standard ISO 19152:2012: *Land Administration Domain Model (LADM)*.

Namen prispevka je podati širok pregled mednarodno prepoznanih objav in s tem predstaviti razvoj področja 3D-katastra nepremičnin v preteklih desetletjih. Na podlagi obravnavanih objav smo analizirali aktualne raziskovalne teme, ki na mednarodni ravni oblikujejo osrčje raziskovalnega dela na tem področju.

2 UPORABLJENA METODOLOGIJA IN VIRI

S področjem razvoja konceptov 3D-katastra ter tehničnih in pravnih rešitev za uvedbo 3D-katastra se ukvarjajo raziskovalci in razvijalci z različnih področij. Skupno vsem je, da se osredotočajo na precej specifično domeno, to je kataster nepremičnin, ki tako združuje dognanja na svetovni ravni. Glavni viri za našo raziskavo so bili dosegljivi viri in zapisi tematske delovne skupine za 3D-kataster mednarodnega združenja FIG¹, ki je že leta 2001 organizirala prvi mednarodni forum, s čimer je želela prispevati k razvojnim rešitvam na področju 3D-katastra nepremičnin. Pomemben vir za naše delo so bile objave v dveh tematskih številkah mednarodne znanstvene revije *Computers, Environment and Urban Planning* iz let 2003 in 2013, kjer je objavljen tudi pregled vsebin razprav v okviru organizacije FIG do leta 2012 (Oosterom, 2013), ter objave v reviji *ISPRS International Journal of Geo-Information* s tematsko številko *Research and Development Progress in 3D cadastral systems* iz leta 2017. Dodatno smo pregledali doktorske raziskave s tega področja in angleške članke v drugih mednarodnih revijah, ki so objavljeni s

¹ *Fédération Internationale des Géomètres: www.fig.net.*

široko uveljavljenim označevalcem elektronske lokacije DOI (angl. *digital object identifier*). V ta namen smo uporabili iskalnik *CrossRef*², ki je ena izmed rešitev za založnike in omogoča kreiranje navedenega označevalca ter uvrščanje revije v izjemno veliko mednarodno družino elektronskih znanstvenih in strokovnih objav (glej tudi Koler Povh in Lisec, 2015).

3 REZULTATI – PREGLED RAZVOJA PODROČJA 3D-KATASTRA NEPREMIČNIN

Začetki izrazitejšega oblikovanja zamisli o 3D-katastru nepremičnin segajo v leto 1994 z začetkom delovne skupine 7.1 mednarodnega združenja FIG, ki je leta 1998 objavilo vizijo razvoja katastra pod naslovom *Cadastré 2014* (Kaufmann in Steudtler, 1998). V dokumentu je izpostavljena vloga katastra kot pomembnega deležnika pri trajnostnem razvoju in odločitvah v prostoru. V dokumentu so podane pomembne opredelitve, ki med drugim kot osnovni nepremičninski element v katastru namesto parcele (parcelno orientiran kataster) uvajajo splošnejši izraz, to je ‚objekt‘, na katerega so vezane pravice, omejitve in odgovornosti. Kataster naj bi tako celostno izkazoval stanje prostora ter zagotavljal pravno varnost in transparentnost glede pravic, omejitev in odgovornosti, ki se nanašajo na katastrske objekte. Napovedana sta bila konec ločevanja opisnih in grafičnih podatkov v katastru ter uvedba računalniškega modeliranja, ki nadomešča analogno katastrsko kartiranje, oboje kot posledica hitrega razvoja informacijske tehnologije. Navedene nove opredelitve in usmeritve so med drugim spodbudile razpravo o uvajanju tretje prostorske razsežnosti v nepremičninske evidence.

3.1 Raziskave na področju 3D-katastra nepremičnin v obdobju 2000–2010

Prvi rezultati raziskav, ki odpirajo raziskovalno področje 3D-katastrov nepremičnin in močno vplivajo na nadaljnjo mednarodno raziskovalno dejavnost, so bili objavljeni že na prelomu tisočletja (Stoter, 2000; Stoter in Zevenbergen, 2001). Avtorja ugotavljata, da registracija nepremičnin v dveh razsežnostih v številnih primerih ne prinaša zadostne pravne varnosti glede pravic in omejitev na nepremičninah, prav tako ne zadošča drugim funkcionalnostim sistema zemljiške administracije.

3.1.1 Prve mednarodno prepoznavne raziskave, razprave in objave

Že navedeno raziskovalno delo na Tehniški univerzi v Delftu na Nizozemskem pomeni uvod v prvo delavnico na temo 3D-katastrov nepremičnin v letu 2001, ki je bila organizirana pod okriljem zveze FIG, s tem pa se je razširilo zanimanje in utrdil položaj tematike 3D-katastrov v raziskovalni sferi. Uvedena je bila klasifikacija področja raziskav na pravne, tehnične in organizacijske vidike, ki se je v skoraj nespremenjeni obliki ohranila vse do danes. Na delavnici so prevladovali predstavitve sistemov zemljiške administracije posameznih držav, obstoječih načinov reševanja zapletenih primerov registracije nepremičnin, kjer obstaja potreba po višinski razdelitvi pravic, in možnosti za nadaljnji razvoj (Grinstein, 2001; Huml, 2001; Menda, 2001; Onsrud, 2001; Ossko, 2001; Rokos, 2001; Viitanen, 2001). Med njimi najdemo tudi predstavitev takrat uvedenega Katastra stavb v Sloveniji (Pogorelčnik in Korošec, 2001).

Ugotovitve z navedene delavnice sta predstavila Lemmen in Oosterom (2003) kot uvod v tematsko številko mednarodne revije *Computers, Environment and Urban Planning*, kjer so objavljeni izbrani

² *CrossRef*: www.crossref.org, nazadnje pregledano 10. 1. 2018.

prispevki z delavnice. Molen (2003) v svojem delu izpostavi, da spremembe kompleksnih sistemov, kot je kataster, vedno zahtevajo tudi organizacijske spremembe v institucijah in da morajo le-te slediti tehnološkemu napredku. Posebej je izpostavljena dilema oziroma razlika med objekti pravnega pomena in objekti, ki predstavljajo fizične strukture v prostoru. Onsrud (2003) predstavi novo pravno ureditev na Norveškem, ki je bila v procesu sprejemanja in omogoča registracijo 3D-nepremičninskih enot za potrebe ureditve pravic in omejitev na grajenih objektih. Predstavljena je tudi možnost kombinacije navedene ureditve z obstoječo, ki temelji na konceptu etažne lastnine. Takratni sistem registracije nepremičnin na Norveškem je še v celoti temeljil na 2D-parcelah, deloma celo še v analogni obliki. Avtor v bližnji prihodnosti ni videl realnih možnosti, da bi pravno veljavne 3D-nepremičninske enote tudi tehnično lahko registrirali kot 3D-objekte. Velik izziv, ki je še vedno aktualen na področju 3D-katastra, je bil način učinkovitega modeliranja katastrskih podatkov v informacijskih sistemih, kar se odraža v več objavljenih prispevkih navedene tematske številke (Billen in Zlatanova, 2003; Stoter in Ploeger, 2003; Tse in Gold, 2003). Tse in Gold (2003) predlagata za modeliranje geometrije in topologije 3D-katastrskih objektov mrežo nepravilnih trikotnikov, kar utemeljita z izvedljivostjo predlagane rešitve. Tudi Billen in Zlatanova (2003) se ukvarjata z načinom modeliranja prostorskih objektov, s poudarkom na njihovih medsebojnih povezavah. Stoter in Ploeger (2003) predstavita možne načine razvoja tradicionalnih sistemov v smeri 3D-katastra.

Doktorska disertacija Stoterjeve (2004) je prvo obširno raziskovalno delo na področju 3D-katastra, v katerem je celovito obravnavan njegov tehnični vidik, dotika pa se tudi pravnega in deloma organizacijskega vidika. Predstavi več primerov iz prakse na Nizozemskem, kjer dvorazsežni pristop v zemljiški administraciji ne zadovoljuje zahtev po pregledni registraciji nepremičnin. Z analizo stanja zemljiške administracije v mednarodnem okolju in podrobnejšo analizo izbranih držav je ugotovila, da takrat nobena država ni imela razvitega sistema za 3D-registracijo nepremičninskih enot, prav tako ta ni bil nikjer predmet aktivnega razvoja. Avtorica izpostavi in jasno utemelji potrebo po uvedbi 3D-katastra na izbranih študijskih primerih. Obravnava predvsem področje modeliranja, upravljanja in predstavitev podatkov o nepremičninah v 3D-okolju. Predstavljene so takratne zmogljivosti informacijske tehnologije za vzpostavitev podatkovnih baz, rešitve za shranjevanje 3D-geometrije, postopki za preverjanje pravilnosti zapisanih podatkov in funkcije za upravljanje podatkov. V okviru doktorskega raziskovalnega dela je avtorica razvila tri različne katastrske podatkovne modele. Pri prvem gre za nadgradnjo obstoječih katastrskih sistemov s shranjevanjem povezav do 3D-podatkov, ki so shranjeni ločeno. Hibridni model ohranja obstoječo vlogo tradicionalnega 2D-katastra kot podlago, na katero se vežejo pravice, omejitve in obveznosti, a dovoljuje registracijo 3D-objektov za namene jasnejšega prikaza stanja pravic in omejitev v prostoru v posebnih primerih. Pravi 3D-kataster omogoča registracijo prostorninskih parcel. 3D-parcele prevzamejo vlogo katastrskih objektov – parcele v katastru niso več opredeljene kot 2D-poligon, ampak kot 3D-telo – pri tradicionalnih parcelah brez vertikalne razmejitve pa kot pokončni stolpi, ki vertikalno niso omejeni. Gre torej za prostorninsko razdelitev celotnega prostora s 3D-nepremičninskimi enotami.

Tu velja omeniti še dejavnosti Ekonomske komisije Združenih narodov za Evropo, ki je leta 2004 z namenom podpore razvoju učinkovitih sistemov zemljiške administracije objavila dokument z usmeritvami, s poudarkom na nepremičninskih enotah in objektnih identifikatorjih (United Nations Economic Commission for Europe, 2004), ki pomembno izpostavlja vlogo sodobnega katastra z ekonomskega vidika. Dokument naj bi prispeval k uskladitvi terminologije in razumevanju razlik med sistemi posa-

meznih držav ter tako omočil lažje mednarodno sodelovanje in izmenjavo podatkov na tem področju. Deloma se dotika tudi problematike tretje prostorske razsežnosti nepremičninskih enot, etažne lastnine in območij mineralnih surovin.

3.1.2 3D-kataster in podatkovni modeli

Uvedba 3D-katastra ne pomeni le uvedbe shranjevanja dodatne prostorske razsežnosti, ampak prinaša korenite spremembe celotnega katastrskega podatkovnega modela. Začetek razvoja na področju 3D-katastra konec devetdesetih sovpada z intenzivnim obdobjem uvajanja računalniškega modeliranja tudi na področju zemljiške administracije. V letu 2003 je bil z željo po poenotenju konceptov in podatkovnih modelov nacionalnih sistemov objavljen prvi predlog katastrskega podatkovnega modela CCDM³ (Oosterom in Lemmen, 2003). 3D-kataster je izpostavljen kot poseben primer, ki je opredeljen kot možnost za nadgradnjo oziroma razširitev osnovnega katastrskega podatkovnega modela skupaj s časovnim vidikom (Oosterom, Lemmen in Molen, 2004). Pri slednjem se avtorji sklicujejo na raziskavo Stoterjeve (2004).

3D-modeli fizičnih objektov (stavbe in infrastruktura) niso vključeni v osnovni podatkovni model CCDM, so pa uvrščeni v sklop ustreznih povezanih vsebin. Primarna vodila pri razvoju CCDM so vključitev čim širšega obsega skupnih značilnosti katastrskih sistemov po svetu, upoštevanje izhodišč dokumenta *Cadastre 2014* (Kaufmann in Steudtler, 1998) in mednarodnih standardov (Oosterom *et al.*, 2006). Velika pozornost je bila namenjena določitvi njegovega tematskega obsega; avtorji so osnovni podatkovni model zasnovali zelo ozko in obenem predvideli možnost različnih tematskih razširitev. Takšna zasnova omogoča lažje prilagajanje modela različnim sistemom po svetu in obenem ohranja osnovno raven primerljivosti oziroma skupnih značilnosti katastrskih sistemov. Nadaljnji razvoj modela je prinesel možnost vključitve 3D-parcel ob uporabi koncepta povezanih površin, a z omejitvijo, da je posamezno območje evidentirano izključno v 2D- ali izključno v 3D-obliki. CCDM je neposredni predhodnik modela LADM⁴. Novo ime modela se pojavi v letu 2008 (Groothedde *et al.*, 2008). Zveza FIG ga je predlagala za ISO-standard (Lemmen, Oosterom in Uitermark, 2009) in je od leta 2012 uradno objavljen kot standard ISO 19152:2012 (LADM, 2012).

Že v začetnem obdobju raziskovalne dejavnosti na področju 3D-katastra nepremičnin se pojavljajo raziskave in analize 3D-grafičnih gradnikov, ki naj bi se uporabljali v 3D-katastru (Billen in Zlatanova, 2003; Tse in Gold, 2003). Stoter in Oosterom (2002) predstavita možnosti modeliranja grafičnih gradnikov v okviru SUPB⁵, ki je osnova za upravljanje katastrskih sistemov z informacijsko-tehnološkega vidika. V raziskavah je obravnavano upravljanje 3D-grafičnih gradnikov v SUPB z vidika modeliranja, funkcionalnosti in vizualizacije (Zlatanova, 2006; Khuan, Abdul-Rahman in Zlatanova, 2008). Kot 3D-gradniki se omenjajo tetraedri, poliedri in poligoni. V navedenih delih avtorji ugotavljajo, da je 3D-grafične gradnike sicer mogoče shranjevati, saj SUPB podpirajo shranjevanje točk, linij in poligonov v 3D-prostoru, težave pa vidijo pri njihovem upravljanju, analizah, posredovanju in vizualizaciji. Navedene težave so izvirale iz dejstva, da takrat SUPB še niso podpirali podatkovnega tipa za prostorninske 3D-grafične gradnike in tako tudi niso omogočali upravljanja takšnih podatkov ter analiz v 3D-okolju.

³ *Angl. core cadastral domain model.*

⁴ *Angl. land administration domain model.*

⁵ *Sistem za upravljanje s podatkovnimi bazami.*

Med najpomembnejšimi vidiki upravljanja podatkov je preverjanje njihove skladnosti z njihovo formalno definicijo, kar velja tudi za 3D-prostorske podatke (Kazar *et al.*, 2008; Ledoux, Verbree in Si, 2009). Slednje ima velik pomen tudi na področju 3D-katastrov (Karki, Thompson in McDougall, 2010). V navedeni raziskavi se avtorji niso omejili zgolj na notranjo pravilnost posameznih grafičnih gradnikov, ampak jih obravnavajo v kontekstu 3D-katastrskega sistema, kjer so pomembni medsebojni odnosi 3D-grafičnih gradnikov in odnosi do 2D-parcel.

Med ključnimi podatkovnimi komponentami katastra je poleg prostorskih razsežnosti tudi čas, ki ga lahko pojmuje kot četrto razsežnost stvarnosti. Prve raziskave na tem področju (Oosterom *et al.*, 2006) obravnavajo časovno problematične primere in se osredotočajo predvsem na pomen dodajanja časovne komponente v katastrski podatkovni model, ne glede na to, ali gre za 2D- ali 3D-kataster. Časovni vidik je obravnavan tudi v okviru takrat predlaganega standarda LADM (Döner *et al.*, 2008) na primeru registracije podzemne infrastrukture v različnih državah. Avtorji vzpostavijo povezavo pravnega objekta in fizičnega objekta podzemne infrastrukture prek uporabe operacije območij (angl. *buffer*) in se hkrati oddaljijo od registracije geometrijskih podatkov o fizičnem objektu v katastru. Pomenljiva je teza avtorjev, da zemljiška administracija že od samega začetka upravlja tako s tremi prostorskimi kot tudi s časovno razsežnostjo v skladu s tehničnimi možnostmi, torej v obliki atributnih podatkov. Časovni del podatkovnega modela lahko temelji na registraciji stanj v času, ki se v osnovi uporablja v večini katastrskih sistemov, ali registraciji začetnega stanja in vseh nadaljnjih dogodkov.

3.1.3 Pravni vidik 3D-katastra

V prvem obdobju raziskav na področju 3D-katastra nepremičnin je bila pravna tematika zastopana šibkeje od informacijsko-tehnološko usmerjenih raziskav. Prva celovita in obširna raziskava pravnih vidikov 3D-katastra nepremičnin v širšem mednarodnem okolju prihaja iz Švedske (Paulsson, 2007), kjer se avtorica ukvarja z osnovnim problemom definicije 3D-nepremičninske enote (angl. *3D property unit*). Zaradi univerzalnosti jo opredeli kot prostorsko enoto, ki je horizontalno in vertikalno razmejena. Pravice, omejitve in odgovornosti, ki so tako razmejene v prostoru, razdeli na etažno lastnino in samostojna 3D-območja pravic. Etažna lastnina je obravnavana kot uveljavljen način urejanja pravic, ki so v prostoru horizontalno in vertikalno razmejene, zato je v navedenem delu obravnavana najpodrobneje. Avtorica podrobno in sistematično obravnava in primerja izbrane štiri pravne ureditve, ki imajo različno tradicijo in različne ureditve registracije pravic na nepremičninah: Nemčijo s tradicionalnim sistemom etažne lastnine in kodificiranim pravom, Švedsko s podobnim pravnim sistemom in novo zakonodajo, ki omogoča registracijo neodvisne 3D-nepremičninske enote, ter avstralski državi Novi Južni Wales in Viktorija, z običajnim pravom in zakonodajo, ki dovoljuje vzpostavitev tako etažne lastnine kot tudi neodvisne 3D-nepremičninske enote.

3.1.4 Organizacijski vidik – stanje in perspektive 3D-katastra

V mnogih objavah iz prvega desetletja intenzivnega raziskovanja na področju 3D-katastrov nepremičnin je predstavljeno stanje in perspektive uvedbe 3D-katastra nepremičnin v posameznih državah. V večini so analizirani obstoječi katastrski sistemi s pravnega in tehničnega vidika, zapleteni primeri, kjer je treba registracijo nepremičnine urejati v treh razsežnostih, ter možnosti uvedbe 3D-katastra v posamezni

državi. Med njimi najdemo tudi posamezne konceptualne zasnove, vsem pa je skupno, da obravnavane tehnične rešitve še niso neposredno izvedljive v praksi.

V Izraelu so raziskovali možnosti vzpostavitve 3D-katastra (Benhamu in Doytsher, 2003), kjer so rešitve iskali po načelu večnivojskega katastra, ki bi poleg podatkovnega sloja za tradicionalne parcele lahko vseboval tudi podatkovna sloja za objekte pod in nad površjem (Benhamu in Doytsher, 2001; Benhamu, 2006). Tehnične izzive, vezane na Izrael, pa tudi širše, sta predstavila Peres in Benhamu (2009), ko so se že okrepila prizadevanja za operativno⁶ realizacijo 3D-katastra. Med državami velja izpostaviti še Kitajsko, kjer je zasebna lastnina lahko vzpostavljena le na grajenih strukturah. Tang in Yang (2009) sta razvila konceptualni model, ki bi omogočal registracijo 3D-nepremičninskih enot, a obenem priznavata, da takrat ni bil izvedljiv zaradi pomanjkanja podatkov ter neobstoječih informacijskih in tehnoloških rešitev za shranjevanje in upravljanje 3D-podatkov. V literaturi zasledimo tudi avstralske zvezne države Novi Južni Wales, Viktorija (Paulsson, 2007) in Queensland (Stoter, 2004) s tradicijo pravne ureditve in registracije 3D-nepremičninskih enot. Te so lahko formirane tudi za območja nad ali pod površjem Zemlje, neodvisno od fizičnih objektov. Sistem registracije nepremičnin z vidika shranjevanja podatkov o geometriji nepremičninske enote pa je v vseh navedenih zveznih državah v celoti temeljil na 2D-konceptih.

Norveška je v tem obdobju uveljavila zakonodajo, ki omogoča vzpostavitev samostojnih 3D-nepremičninskih enot (Valstad, 2010). Osnovne značilnosti te zakonodaje je obravnaval že Onsrud (2003). Registracija samostojnih 3D-nepremičninskih enot je mogoča le za namene registracije grajenih objektov (Valstad, 2006), podobno kot na Švedskem (Eriksson, 2005; Paulsson, 2007). V obeh državah katastrski sistem tehnično ni dovoljeval digitalne registracije 3D-geometrije nepremičninskih enot. Registracija posameznega stanovanja kot samostojne 3D-enote ni mogoča niti na Švedskem niti na Norveškem. Slednje je ostalo v domeni etažne lastnine. Poudariti velja, da imata obe državi enoten sistem zemljiške administracije, ki je pred leti nastal z združitvijo nekdanjega dualnega sistema (pravnega in tehničnega). Dejstvo izpostavljamo zaradi organizacijsko-institucionalnega vidika uvajanja 3D-katastra in drugih obsežnejših sprememb v zemljiško administracijo.

V nasprotju z navedenimi državami, ki so v obravnavanem obdobju pogosteje obravnavane zaradi njihovega načina urejanja in registracije 3D-nepremičninskih enot, je Nizozemska ohranjala tradicionalno ureditev katastrskega sistema. Država ima sicer že več desetletij enoten sistem zemljiške administracije znotraj ene organizacije (prej je imela tudi dualni sistem z delitvijo na zemljiški kataster in zemljiško knjigo). Pogosta pojavnost Nizozemske v raziskavah je predvsem posledica dejavnosti raziskovalcev ter sodelovanja akademske sfere z njihovo geodetsko upravo, kar je v začetku desetletja zelo pospešilo raziskave na področju 3D-katastru (Stoter in Ploeger, 2003; Stoter in Salzmann, 2003; Stoter, 2004).

Slovenija je v prvem desetletju z uvedbo katastra stavb vzpostavila podlago za razvoj 3D-katastra (Pogorelec in Korošec, 2001; Rijavec, 2009), a vse do danes ni bilo intenzivnejšega razvoja v tej smeri. Velika težava pri tem so slaba povezava zemljiških parcel in stavb, nedorečenost katastrskega evidentiranja infrastrukturnih objektov, ki niso stavbe, ter pomanjkljivi podatkovni model katastra stavb (glej tudi Drobež, 2016; Drobež *et al.*, 2017).

⁶ Z besedo 'operativno' v članku označujemo dejansko uporabo/lizvedbo nečesa v katastrskem sistemu posamezne države.

Glede operativne izvedbe 3D-katastra nepremičnin v praksi tudi ob koncu desetletja v literaturi večkrat zasledimo, da je potreben nadaljnji razvoj na vseh ustreznih področjih. Izstopa le pravno področje v tistih državah, kjer pravnih omejitev za registracijo 3D-nepremičninskih enot ni. Zanimivo je, da Čağdaş in Stubkjær (2009) v raziskavi, v kateri sta analizirala metodološke pristope doktorskih raziskav na področju razvoja katastrskih sistemov, ne izpostavljata 3D-katastra in navedenih doktorskih raziskav (Stoter, 2004; Paulsson, 2007) kot pomembnega dela razvoja sodobnih katastrov.

3.2 Raziskave na področju 3D-katastra po letu 2010

V letu 2011 je bila opravljena raziskava med člani FIG-ove delovne skupine o 3D-katastrih nepremičnin, v kateri je sodelovalo 36 držav članic navedene skupine (Oosterom *et al.*, 2011). Vsebina vprašalnika je bila osredotočena na inventarizacijo stanja po državah v letu 2010 in njihova pričakovanja za leto 2014. Rezultati zelo pomembno prispevajo k raziskavam o 3D-katastrih, saj omogočajo prost dostop do obširnega nabora podatkov o katastrskih sistemih številnih držav. Avtorji raziskave ugotavljajo, da imajo države različne katastrske sisteme, iz česar izhaja tudi neenotno pojmovanje 3D-katastra. Razlike so predvsem glede razumevanja povezave tradicionalne 2D-parcele in 3D-nepremičninskih enot s fizičnimi strukturami. Nobena od držav takrat še ni imela razvite možnosti shranjevanja in upravljanja 3D-podatkov o nepremičninskih enotah v katastrih. Glede načrtov in pričakovanj za leto 2014 je bila večina zelo zadržanih. Leta 2014 so predstavniki 31 držav podali odgovore na drugi, dopolnjen vprašalnik o stanju in pričakovanjih na področju 3D-katastra za leto 2018 (Oosterom, Stoter in Ploeger, 2014). V vseh državah, v katerih je pravni sistem omogočal registracijo 3D-nepremičninskih enot, so načini registracije, shranjevanja in upravljanja podatkov še vedno temeljili na 2D-zasnovanem katastru. Državam je bila skupna večinska »neskladnost« digitalnih katastrskih podatkovnih baz s shemo standarda ISO 19152:2012 (LADM, 2012). Glede shranjevanja 3D-podatkov v digitalni obliki močno izstopa Kitajska, ki v odgovorih na vprašalnik navaja, da njihova podatkovna baza omogoča shranjevanje, preverjanje in upravljanje 3D-geometrije nepremičninskih enot. A pri kitajskem primeru hkrati zasledimo izjemno majhno skupno število parcel glede na velikost države, zato gre sklepati, da opisano stanje velja le za omejena (urbana) območja Kitajske. Tudi kasnejše raziskave (Guo *et al.*, 2013; Ho *et al.*, 2013; Dimopoulou, Karki in Roič, 2016; Stoter *et al.*, 2017) potrjujejo, da Kitajska v začetku desetletja ni imela polno operativnega sistema 3D-katastra.

Leta 2011 je na Nizozemskem potekala druga delavnica o 3D-katastru, kar je bilo torej deset let po prvi. Zanimivo je, da je bila takrat napovedana naslednja, tretja delavnica v dveh ali treh letih, a je bila izvedena že v naslednjem letu, kar kaže na povečano zanimanje za raziskave in izmenjavo znanja na mednarodni ravni na tem področju. V poročilu o delavnici leta 2011 (Banut, 2011) je predstavljeno stanje na posameznih razvojnih področjih 3D-katastra, ki so deljena na pravne vidike, prve registracije 3D-nepremičninskih enot, upravljanje 3D-prostorskih podatkov in vizualizacijo, posredovanje in dostopnost podatkov o 3D-nepremičninskih enotah:

- Na pravnem področju je izpostavljena težava neuskladenosti terminologije ter različnih opredelitev 3D-katastra.
- Več kot dve tretjini prispevkov opisujeta sisteme zemljiške administracije posameznih držav in načine urejanja višinske delitve nepremičninskih enot v luči aktualnih raziskav in podatkovnih modelov.
- Na področju upravljanja digitalnih 3D-prostorskih podatkov, predvsem področja analiz in izvajanja

operacij v SUPB in GIS⁷, je prepoznan močan zaostanek za področjem 3D-vizualizacije prostorskih podatkov, ki je v prvem desetletju tega tisočletja močno napredovalo. Izpostavljena je pomembnost spletne dostopnosti 3D-podatkov katastrov nepremičnin in tehnik 3D-vizualizacije na spletu.

Tematski poudarek tretje delavnice leta 2012 je bil na razvoju in dobrih praksah na področju 3D-katastra (Oosterom, 2012). Izražena je bila predvsem potreba po večjem številu raziskav in primerjalnih analiz pravnih ureditev v različnih državah in zahteva po uporabi obstoječih standardov, tako s področja modeliranja nepremičninskih enot (LADM) kot tudi s področja modeliranja fizičnih prostorskih struktur v informacijskih sistemih zemljiške administracije. Med drugim je bil poudarjen pomen vizualizacije 3D-nepremičninskih objektov, saj so potrebe in izzivi drugačni kot pri vizualizaciji bolj razširjenih 3D-modelov mest in pokrajin.

Izhajajoč iz prispevkov z delavnic in konferenc združenja FIG leta 2011 in 2012, Oosterom (2013) podaja oris razvoja na področju 3D-katastrov, kjer predstavi tudi najpomembnejše teme za prihodnje raziskave. Izpostavljamo predvsem tematike, ki so še vedno aktualne na mednarodni ravni:

- Že navedeno pomanjkanje raziskav na pravnem področju sta Paulsson in Paasch (2013) utemeljila na podlagi študije 156 objav angleških člankov med letoma 2001 in 2011. Ugotovila sta pomanjkanje predvsem terminoloških in primerjalnih raziskav, ki bi zajemale več držav in pravnih ureditev na področju 3D-katastra.
- Višine in višinske sisteme 3D-katastrov sta prvič izčrpnje obravnavala Navratil in Unger (2013). Predstavila sta splošno problematiko višinskih referenčnih sistemov in omejitve ter zahteve 3D-katastrov, tudi na primerih iz prakse. Največ pozornosti je namenjene analizi prednosti in slabosti uporabe absolutnih in relativnih višin v 3D-katastru.
- Zelo pomemben element, ki ima velik vpliv na dinamiko uveljavitve 3D-katastra, je razmerje med stroški in koristmi, ki jih prinaša. Ena od redkih takšnih raziskav na primeru Trinidada in Tobaga ugotavlja pozitivno razmerje stroškov in koristi na urbanih in gosto poseljenih območjih ter nahajališčih naravnih surovin (Griffith-Charles in Sutherland, 2013). Avtorja ugotavljata, da je smiselno proučiti možnosti vpeljave 3D-katastra le na nekaterih območjih, kjer koristi odtehtajo stroške.
- Operativna uvedba 3D-katastra med drugim zahteva določitev jasnih pravil glede razmejitev prostora na 3D-nepremičninske enote ter modeliranja teh enot v 3D-okolju, skupaj s postopki preverjanja njihove skladnosti s postavljenimi pravili. Slednje je v treh prostorskih razsežnostih veliko težavnejše, saj je nabor pravil obširnejši, pa tudi postopki preverjanja skladnosti s njimi so zahtevnejši kot v tradicionalnem 2D-katastru. Karki, Thompson in McDougall (2013) so navedeno področje podrobno proučili, oblikovali nekatere rešitve ter nabor izzivov in nerešenih vprašanj. Avtorji sklenejo, da razvoj sistemov zemljiške administracije v smeri 3D-katastra ni mogoč v kratkem časovnem obdobju. Ena od rešitev je postopno prilagajanje obstoječih sistemov, kar zagovarjajo Guo *et al.* (2013). Avtorji na primeru kitajskega katastra izhajajo iz obstoječega pravnega sistema in 2D-podatkovnega modela, v katerega vključijo elemente 3D-katastra. Članek je zanimiv tudi za primerjavo z rezultati že navedene raziskave o razvoju 3D-katastra (Oosterom, Stoter in Ploeger, 2014), kjer bi lahko za Kitajsko napačno sklepali, da je že pred letom 2014 imela polno delujoč sistem 3D-katastra.
- Primerjava katastrskih sistemov med posameznimi državami je zaradi njihove različnosti zelo težavna. Pouliot, Vasseur in Boubehrezh (2013) so primerjali modele katastrskih sistemov Francije

⁷ Geografski informacijski sistem.

in Kanade, s poudarkom na tretji prostorski razsežnosti, na podlagi standarda LADM (2012). Kot najzahtevnejši del izpostavijo transformacijo podatkovnega modela posameznega sistema v standardno shemo LADM, kar v nadaljevanju omogoča neposredno medsebojno primerjavo katastrskih sistemov, njihovih razredov in atributov. Predlagajo in utemeljijo tudi vključitev prostorninske geometrije v standard, s čimer bi povečali uporabnost standarda LADM tudi na področju 3D-katastra.

Prispevki četrte delavnice združenja FIG na temo 3D-katastra iz leta 2014 so vsebinsko večinoma tehnično usmerjeni, ne glede na pozive o pomanjkanju obravnave pravne problematike (Paulsson in Paasch, 2013):

- Pravni vidik je kot glavna tematika na delavnici obravnavan le v eni objavi v obliki nacionalne študije za Poljsko (Karabin, 2014).
- Izrazito se je povečala obravnava ISO-standarda LADM (2012) in odprtega standarda CityGML združenja OGC⁸ (CityGML, 2012), ki ju v kombinaciji ali samostojno zasledimo v osmih objavah. Število raziskav in predstavitev sistemov po posameznih državah je glede na prejšnje delavnice upadlo. Med objavami sta zanimivi dve (Almeida *et al.*, 2014; El-mekawy, Paasch in Paulsson, 2014), ki med prvimi obravnavata področje prostovoljnega zbiranja prostorskih podatkov in povezavo informacijskega modeliranja stavb (BIM⁹) s 3D-katastrom. Izpostavljeni tematiki sta predstavljeni kot izziv za 3D-kataster, saj sta obe področji danes raziskovalno zelo intenzivni na širšem področju geo-znanosti. BIM predstavlja potencial za razvoj večnamenskega 3D-katastra in pomembno področje prihodnjih raziskav (Rajabifard, 2014).
- Vsebina objav kaže na večje zanimanje za raziskave na področju 3D-vizualizacije (Navratil in Fogliaroni, 2014; Pouliot, Wang in Hubert, 2014; Ribeiro, de Almeida in Ellul, 2014), kar potrjujeta tudi obsežni doktorski disertaciji iz tega obdobja (Shojaei, 2014; Wang, 2015). Wang (2015) se je osredotočil na ocenjevanje primernosti načinov vizualizacije 3D-modelov za primer prikaza etažne lastnine, med tem ko se je Shoaiei (2014) ukvarjal predvsem z analizami uporabniških zahtev in njihovih potreb.

3.2.1 Izzivi na področju 3D-katastra s pravnega vidika

Kljub relativno skromni obravnavi pravnega vidika 3D-katastra na navedeni FIG-ovi delavnici leta 2014 je področje bilo in je še vedno aktualno na mednarodni ravni. Na področju zemljiške administracije in nepremičninskih evidenc se namreč srečujeta koncepta fizičnega prostora in abstraktnega prostora, kjer se na »abstraktne« prostorske enote nanašajo pravice, omejitve in odgovornosti. Ob nepopolnem poznavanju področja ju lahko enačijo na podlagi pogostega sovpadanja meja fizičnih struktur in meja pravic oziroma omejitev. Razdelitev prostora s pravnega vidika je v osnovi abstraktna, njena povezava s fizičnim prostorom pa je vzpostavljena v različnih oblikah in iz različnih vzrokov, razlikuje pa se med pravnimi sistemi. Področje 3D-katastra je pogosto usmerjeno v obravnavo razdelitve stavb na nepremičninske enote, kjer gre za povezavo med prostorom pravnega pomena in fizičnim prostorom ter njegovimi strukturami (Aien, 2013; Aien *et al.*, 2013, 2015), iz česar izhaja tudi pogosto enačenje fizičnih meja prostora s pravnimi (abstraktnimi). V navedenih raziskavah so avtorji razvili model 3DCDM¹⁰, ki združuje fizične in pravne vidike razdelitve prostora za potrebe 3D-katastra.

⁸ Open Geospatial Consortium: <http://www.opengeospatial.org/>.

⁹ Angl. building information modelling.

¹⁰ Angl. 3D-cadastral domain model.

Razvoj področja 3D-katastra v prvem desetletju je privedel do razhajanj glede pravnih opredelitev nepremičnine v treh razsežnostih (Paasch in Paulsson, 2012). Avtorja ugotavljata, da slednje povzročata težave tudi na raziskovalnem področju, saj so zaradi neenotnih opredelitev temeljnih pojmov omejene možnosti primerjalnih analiz in študij. Kot poudarita, mora biti pravna opredelitev nepremičnine v treh razsežnostih dovolj široka, da je lahko sprejemljiva v večini pravnih sistemov. Poleg tega mora opredelitev takšno nepremičnino jasno in enolično opredeliti ter jo razmejiti od tradicionalne nepremičnine v dveh razsežnostih. Avtorja predlagata univerzalno opredelitev 3D-nepremičnine, kot jo je že predlagana Paulssonova (2007). Z vidika pravno usmerjenih raziskav je zanimiva raziskava Ho *et al.* (2013), kjer avtorji izhajajo iz teze, da je tehnologija dovolj razvita, pa tudi pravni sistemi v številnih državah dovoljujejo registracijo 3D-nepremičninskih enot, zato mora obstajati zaviralna sila, ki preprečuje hitrejšo uveljavljanje 3D-katastra. To silo avtorji pojasnijo in razčlenijo z institucionalno teorijo in utemeljijo, da so razlogi za počasne spremembe v počasnem prilagajanju odgovornih organizacij in močno uveljavljenem 2D-konceptu v sistemih zemljiške administracije. Oosterom in Lemmen (2015) izpostavita 3D- (in 4D-) administracijo kot enega od pomembnejših razvojnih trendov zemljiške administracije in s tem tudi standarda LADM. Predstavita raziskave, ki izhajajo iz prve tematske delavnice po objavi standarda LADM, med katerimi sta tudi dve na temo razvoja 3D-katastra v Koreji in Maleziji (Lee *et al.*, 2015; Zulkifli *et al.*, 2015).

3.2.2 Izzivi pri uveljavljanju 3D-katastra

Posebno poglavje v razvoju 3D-katastra je njegova operativna uvedba. Prve raziskave na to tematično so potekale v okviru nizozemskega projekta, namenjenega podpori prehoda na 3D-kataster, ki temelji na dveh izvedbenih fazah (Stoter, Oosterom in Ploeger, 2012; Stoter, Ploeger in Oosterom, 2013). Prva faza je bila namenjena pridobivanju izkušenj in se v rešitvah prilagaja obstoječim pravnim in tehničnim okvirom. Njen izvedbeni del se nanaša na možnosti registracije nepremičnine na podlagi dokumenta v obliki zapisa PDF, ki vsebuje 3D-geometrijo in je povezan z drugimi podatki o nepremičnini prek povezave v podatkovni bazi. Zanimiva je ocena stroškov registracije in vzdrževanja sistema, ki naj za nove stavbe ne bi bili višji od obstoječih stroškov registracije. Prva faza uvedbe 3D-katastra danes omogoča reševanje nekaterih kompleksnih situacij, predvsem z vidika nedvoumnega prikaza razdelitve na nepremičninske enote, še vedno pa obstoječ 2D-sistem zemljiške administracije v osnovi ostaja nespremenjen. Druga faza je zasnovana veliko ambicioznejše, saj predvideva uvedbo 3D-katastra, ki omogoča celovito digitalno registracijo nepremičninskih enot, vključno z geometrijo, v obliki 3D-objektov (prostorninskih teles) neposredno v podatkovni bazi katastra. V zvezi z drugo fazo je nerešenih veliko vprašanj glede kontrole geometrije, zahtevane položajne in geometrijske natančnosti, podatkovnih formatov, vključitve ukrivljenih ploskev, delno odprtih gradnikov ipd. (Stoter *et al.*, 2017).

V Rusiji so začeli projekt 3D-katastrskega modeliranja v sodelovanju z nizozemskimi raziskovalci. Razvili so prototip, ki se osredotoča predvsem na način modeliranja in prikazovanja 3D-nepremičninskih enot. V načrtih so opredelili pilotni projekt na manjšem območju, kjer bi se približali realni izvedbi registracije. Vandysheva *et al.* (2012) poudarjajo pomen samodejne kontrole ob vpisu novih nepremičninskih enot v smislu skladnosti s predhodno postavljenimi pravili. Kljub intenzivnim naporom za vzpostavitev 3D-katastra in modernizaciji sistema zemljiške administracije v zadnjih letih, ta v Rusiji še vedno temelji na dveh prostorskih razsežnostih (Ilyushina, Noszczyk in Hernik, 2017).

3.3 Aktualne teme in raziskave na področju 3D-katastra

Zadnja delavnica na področju 3D-katastra pod okriljem FIG-a je potekala leta 2016. Da je področje raziskovalno aktivno, med drugim kaže povečano število prispevkov (31) glede na predhodno delavnico (25). Izbrani prispevki so v razširjeni različici zbrani tudi v posebni izdaji mednarodne revije *ISPRS International Journal of Geo-Information* z naslovom *Research and Development Progress in 3D Cadastral Systems 2017*.

Najbolj opazno je ponovno veliko število objav, vezanih na analizo stanja v posameznih državah in različnih možnosti za razvoj sistemov zemljiške administracije, med katerimi prevladujejo objave, ki se osredotočajo na tehnične rešitve modeliranja 3D-nepremičninskih enot v informacijskih sistemih zemljiške administracije (Araújo in Oliveira, 2016; Dimas, 2016; Soon, Tan in Khoo, 2016; Gulliver, Haanen in Goodin, 2017). Na to področje se nanašajo tudi druge objave v mednarodno odmevnih revijah. Tako Aien *et al.* (2017) izpostavijo šest najbolj uveljavljenih podatkovnih modelov v katastru, kjer je so se zaradi različnosti sistemov zemljiške administracije pojavili številni podatkovni modeli. Med njimi avtorji izpostavljajo tri (LADM, ePlan, ArcGIS Parcel Data Model) in jih podrobneje analizirajo z vidika uporabnosti za 3D-kataster. Podatkovni model 3DCDM, ki ga je v okviru doktorske raziskave razvil vodilni avtor, v raziskavi ni vključen, niti ni v njej omenjen. Avtorji ugotavljajo, da nekateri obravnavani podatkovni modeli omogočajo modeliranje 3D-nepremičninskih enot, a pri vsakem razkrijejo pomembne omejitve za razvoj 3D-katastra.

Na raziskovalni ravni je spet močnejše zastopano pravno področje raziskav (Kitsakis in Dimopoulou, 2017; Vučić *et al.*, 2017), na čelu z obširno primerjalno študijo med izbranimi državami (Kitsakis, Paasch in Paulsson, 2016; Paasch *et al.*, 2016). Kitsakis, Paasch in Paulsson (2016) predstavijo pravno opredelitev 3D-nepremičninskih enot v različnih državah (Avstrija, Brazilija, Hrvaška, Grčija, Poljska in Švedska) in načrte za prihodnji razvoj. Švedska, kot edina od naštetih držav, v pravnem sistemu ne omejuje registracije 3D-nepremičninskih enot, a upravljanje podatkov, tako kot v drugih državah, tudi na Švedskem še vedno temelji na 2D-konceptih.

Na področju modeliranja in upravljanja podatkov v 3D-katastrih je zanimiva raziskava Janečka in Součka (2017). Avtorja predstavljata aktualno stanje na širšem področju 3D-geoinformatike, ki zajema koncepte, podatkovne modele, standarde in operacije, povezane s 3D-prostorskimi podatki. Poudarek je na trenutnih zmogljivostih prostorskih podatkovnih baz z vidika modeliranja in upravljanja 3D-prostorskih podatkov. Izredno aktualna tema je povezava oziroma vključevanje podatkov BIM v podatkovni model 3D-katastra. Vse več raziskav se v povezavi s podatki BIM usmerja tudi na modeliranje notranjosti stavb za potrebe registracije nepremičninskih enot (Oldfield *et al.*, 2016; Atazadeh, 2017). Atazadeh *et al.* (2017) obravnavajo BIM kot osnovo za upravljanje pravic in omejitev na stavbah. Predlagajo razširitev podatkovnega modela tako, da bi ta podpiral tudi vnos podatkov o pravicah in omejitvah v stavbah in njihovo upravljanje. Med drugim se avtorji dotikajo aktualnega vprašanja odnosa 3D-enot pravnega pomena in fizičnega modela stavbe. Poleg prednosti avtorji navajajo omejitve predlaganega pristopa, ki vključujejo institucionalne ovire, preobširno podatkovno strukturo ter problem neuskladenosti med načrtovanim in dejansko zgrajenim objektom.

V modeliranje notranjosti stavb je usmerjeno raziskovalno delo Zlatanove *et al.* (2016), kjer je prvič v okviru raziskav na področju 3D-katastra uporabljen v letu 2014 sprejet standard OGC – IndoorGML

(2014). V prispevku avtorji obravnavajo možnosti za povezavo navedenega standarda s standardom LADM. Razširjene raziskave v tej smeri predstavlja Alattas *et al.* (2017). Standard IndoorGML temelji na večslojnem prostorsko-dogodkovnem modelu, prvotno namenjenem podpori navigaciji v notranjosti stavb, predlaganem v letu 2009 (Becker, Nagel in Kolbe, 2009). Navedena skupina avtorjev je bila vodilna tudi pri razvoju starejšega standarda za modeliranje mest in pokrajin v 3D-okolju CityGML. Standard IndoorGML uvaja celični pristop modeliranja notranjosti stavb, ki je po načelu dualnosti (Munkres, 1984) povezan z matematičnim grafom. Ta omogoča izvajanje algoritmov iskanja optimalnih poti v podporo navigaciji, pa tudi drugih algoritmov, ki temeljijo na topoloških odnosih med grafičnimi gradniki. Standard omogoča razširitve podatkovnega modela v obliki razširitvenih modulov za različna področja. Kang in Li (2017) sta posebej izpostavila možnost realizacije razširitvenega modula standarda IndoorGML za področje 3D-katastra. Povezovanje modelov mest in modelov notranjosti stavb ter podzemnih objektov je prepoznan raziskovalni problem tudi v skupini strokovnjakov za področje globalnih prostorskih informacij pri Združenih narodih UN-GGIM (2015).

4 SKLEP

Začetki uveljavljanja termina 3D-kataster segajo v čas nastanka dokumenta *Cadastre 2014* (Kaufmann in Steudtler, 1998). Za opredmetenje zapisanih ciljev je bila leta 2001 izvedena prva delavnica pod okriljem FIG, ki je spodbudila raziskave na področju 3D-katastra. Jasneje so se določili različni vidiki razvoja 3D-katastrov: pravni, tehnični in administrativni, od katerih sta prva dva v raziskavah močneje zastopana. Za prvo desetletje je značilno veliko število analiz sistemov zemljiške administracije v posameznih državah in predlogi za njihovo nadgradnjo. Skupne ugotovitve so bile, da je za vzpostavitev 3D-registracije potreben dodaten razvoj na vseh navedenih področjih raziskovanja.

Na tehničnem področju raziskovanja 3D-katastrov je velik pečat pustila doktorska disertacija Stoterjeve (2004). Večina raziskav, ki sledijo, se namreč navezuje na njene izsledke, opredelitve in predloge. Na pravnem področju izstopata Švedska, ki je leta 2004 v svoj pravni sistem uvedla možnost registracije 3D-nepremičninske enote, in Avstralija z dolgo tradicijo možnosti registracije samostojnih 3D-nepremičninskih enot. Med najodmevnejšimi študijami stanja pravnih sistemov na področju 3D-katastra je doktorska disertacija Paulssonove (Paulsson, 2007), ki podaja celovit pregled in uvid v pravni vidik 3D-katastra. Dokument *Cadastre 2014* je sprožil tudi začetne zasnove podatkovnega modela CCDM katerega namen je poenotenje ključnih sestavin sistemov zemljiške administracije po svetu. Gre za neposrednega predhodnika mednarodnega standarda LADM (2012), ki v osnovi ne omejuje evolucije tradicionalnega 2D-katastra v 3D-kataster.

Zadnje desetletje raziskav na področju 3D-katastra zaznamuje predvsem objava standardov LADM (2012) in CityGML (2012) ter tudi IndoorGML (2014). V večini raziskav v tem obdobju se proučujejo možnosti uporabe navedenih standardov, analizirajo prednosti in slabosti posameznih standardov ter se medsebojno primerjajo. Manj raziskav se nanaša na pravni vidik, kar ugotavljata že Paulsson in Pasch (2013). Nizozemski raziskovalci so v tem obdobju pomembno prispevali k uvajanju konceptov 3D-katastra v prakso. Ko se bo za razvoj katastra v smeri podpore tretji razsežnosti odločilo več držav, se bodo okrepile tudi raziskave. Raziskovalni izzivi na področju 3D-katastra se nadalje nanašajo na integracijo podatkov iz drugih domen, predvsem so pri tem aktualne raziskave glede uporabe oziroma vključevanja

podatkov BIM v podatkovni model 3D-katastra in nasprotno. Dodatno je aktualna obravnava oziroma modeliranje notranje strukture stavb, ki je zahtevna tako z vidika strukture podatkov in kompleksnosti podatkovnih modelov kot tudi z vidika pridobivanja podatkov in integracije modelov notranjosti stavb in zunanjih modelov mest ter pokrajin (UN-GGIM, 2015).

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